POSITIONS OF MONTHLY MEAN TROUGHS AND RIDGES IN THE NORTHERN HEMISPHERE, 1949–1963

L. P. STARK

Weather Bureau, Environmental Science Services Administration, Washington, D.C.

ABSTRACT

Positions of trough lines and ridge lines for each month are shown as they were transcribed from monthly 700-mb. charts for 1949–63. This is the first time that 15 years of reliable upper-air analyses were available over all continents in the Northern Hemisphere.

The preference of these circulation features for particular geographical areas in certain months or seasons is clearly depicted. This is a rather small sample, but if one excludes possible secular changes, these charts should be fairly representative of longer periods, especially in those areas where frequency of occurrence was maximum or minimum.

1. INTRODUCTION

Methods of long-range forecasting differ among several nations [1, 2] but its practitioners usually rely on many subjective procedures while making a prognosis. In the Extended Forecast Division (EFD), National Meteorological Center, U.S. Weather Bureau, there has been encouraging progress in applied research to objectivize some aspects of long-range forecasting [2, 3, 4]. But there are many unresolved problems, some of which are unique [5] and have not been amenable to numerical treatment. Until the dynamics of the atmosphere are more thoroughly understood and incorporated into numerical models, it will be necessary to utilize historical information for whatever clues will assist the forecaster.

Many of these climatological aids are used to supplement the various approaches to long-range forecasting. One such device that has been very useful in EFD is the frequency of troughs and ridges on 30-day and 5-day mean 700-mb. charts. An early study [6] depicted the occurrence of these large-scale features as isolines of percentage frequency in a given month in the Northern Hemisphere for the period 1933–55. Prior to the late 1940's there was little upper-air information from parts of Europe, much of Asia and Africa, and from oceanic areas. In some instances only 6 years of data were available from which to derive the percentage frequencies while in North America and western Europe 23 years of non-homogeneous data were used. The current study eliminates the above deficiency by excluding data prior to 1949, and including homogeneous data through 1963.

Charts of frequency of troughs and ridges in the planetary flow are a useful tool to the meteorologist making a 30-day forecast. These charts indicate not *only the most likely* position for troughs and ridges but they also show the longitudinal variability (based on 15 years of data) that must be considered. Of perhaps equal importance the charts show where there is least probability of occurrence of a trough or ridge. In contrast, normal charts cannot delineate more than a time-smoothed approximation that blends features into broad, diffuse troughs and ridges of little prognostic value by themselves.

2. CONSTRUCTION OF CHARTS

Separate charts of troughs and ridges were prepared for each calendar month (figs. 1–24) and for the 30-day period from each mid-month to mid-month for 1949–63 (not shown here, but used routinely in EFD). Thirty-day mean 700-mb. charts were used in this project to oonform with the charts used operationally in EFD from which twice monthly circulation forecasts are made. Another reason for this choice was the comprehensive record of 30-day mean 700-mb. charts on file in EFD that were on a map base suitable for transcribing. From this file each significant trough and ridge for the appropriate 30-day period was transferred to a blank map and represented by a line extending generally north-south.

For consistency and objectivity a trough was defined as the tangency of the lowest height with latitude. Areas of cyclonic (anticyclonic) curvature were not considered troughs (ridges) unless the criterion above was satisfied.

There were two other requirements. In the study a trough (ridge) was considered significant only if it extended through 5° lat. or more and its intensity at a given latitude was more than 10 ft. lower (higher) than the 700-mb. height 5° long. on either side. (This latter provision was subjectively determined on charts for the last four years of the sample since height values were not hand-plotted on machine-drawn charts.)

Trough and ridge lines extend only to 15° N. lat., the limit of the EFD grid for which data were compiled.

3. DISCUSSION OF CHARTS

Positions of 30-day mean troughs and ridges varied from month to month with the changing seasons. These shifts in position were frequently small but not consistently so. At times there was considerable variability in adjacent months especially in the transitions from spring to summer and fall to winter. Frequency of occurrence of mean troughs and ridges depended principally on orographic influences, ocean-continent boundaries, and seasonal changes in heating. There may be other factors that contributed to the obvious preference of troughs and ridges for certain areas, but the variations from season to season appear to have been related mostly to varying heat sources and sinks.

Some care must be taken that these charts are not considered as characteristic of long-period climatological averages. There are exceptions, of course. For example, figure 1, January trough lines, shows a large zero frequency area in the prairies and mountains of western Canada. This area was also free of troughs in the period 1933–55 [6]. Thus one can be reasonably certain that it is climatologically unlikely to have a 30-day mean trough there in January.

In those instances when troughs or ridges have occurred over a fairly broad area one may be tempted to accept some average as the most likely forecast position. This must be avoided if large errors are to be kept to a minimum. In figure 2, an integrated position for a January ridge line in the eastern Pacific at 30° N. lat. might be chosen near 135° W. long. Since this occurred only once in the 15-yr. period, it may be sufficient reason for not forecasting a ridge line there. The reader will thus recognize that the ridge on a normal flow chart may be of questionable prognostic value.

NORTH AMERICA

Probably the most prominent feature over North America was the recurrent ridge over the Rocky Mountains. From Alaska or the Yukon to the Canadian border this ridge was observed every month of the year with a fairly high frequency of occurrence. These ridges extended into the Western States in most months, and from July to November (figs. 14, 16, 18, 20, 22) they frequently reached Mexico. During June (fig. 12) there was no well-defined maximum in this area. Instead the ridges were spread diffusely from the Rocky Mountain States to the Mississippi Valley where there was a concentration of ridges. In the colder months (figs. 22, 24, 2, 4) ridges were seldom observed between the Rockies and the Appalachians and in Canada from the Rockies to Davis Strait.

Troughs near Baja California were so frequent that they were essentially a permanent feature of the monthly mean circulation. In June, July, and August (figs. 11, 13, 15) these troughs were about 10° long. west of Baja California and also extended northward along the west coast to middle latitudes.

In eastern North America there was a high incidence of trough lines with the least concentration in March (fig. 5) and October (fig. 19). These troughs appear to have been anchored largely by the ridge in the West and by the baroclinic environment favorable for troughs. From May to October (figs. 9, 11, 13, 15, 17, 19) these troughs were mostly off the east coast of the United States, perhaps because trough concentration off the west coast of the United States usually is associated with mean troughs off the east coast.

Over southeastern United States the ridge left the area in most years in June, July, and August (figs. 12, 14, 16) and reappeared over the Great Plains in response to continental heating and northward migration of the westerlies. The frequency of ridges in the Southeast was relatively high in September (fig. 18) but from October to December (figs. 20, 22, 24), there were fewer ridges as the belt of subtropical high pressure receded and troughs became more numerous.

Changes in percentage frequency between the first study [6] and this current report were notable in some instances. In the ridges just discussed maximum occurrence in January (fig. 2) was at least 50 percent compared with 20 percent earlier. Other major discrepancies include an increase in ridges in the Utah-Idaho region in September (fig. 18) from 20 to 50 percent while in the northern U.S. Rockies there was a decrease from about 45 to 25 percent. Trough line occurrence in the current study was also quite different than earlier. In February (fig. 3) from Texas to the western Great Lakes there was an increase from about 10 percent to more than 50 percent; in April (fig. 7) in the same area the increase was from less than 10 percent to about 60 percent.

NORTH ATLANTIC OCEAN

Troughs were found at all latitudes and longitudes in the Atlantic at one time or another but with few well-defined areas of maxima in the central portion. In June, July, and August (figs. 11, 13, 15) there were very few troughs in the central Atlantic in middle latitudes as the subtropical ridge dominated this area.

Many of the troughs at the lower latitudes in the North Atlantic were easterly troughs, especially those that extended only a short distance north of 15° N. lat. Many, however, were extensions of polar troughs that remained after increased westerly flow in more northerly latitudes produced shearing.

Ridges were much more common in the North Atlantic than were troughs, excluding of course the near-continent areas. This agrees generally with the earlier article on

FIGURES 1–24.—Positions of 30-day mean trough lines (odd figure numbers) and ridge lines (even figure numbers) north of 15° N. lat. for 1949–63. Trough lines were drawn connecting minimum latitudes of height contours, ridge lines connecting maximum latitude of contours. Areas of maximum curvature that did not meet these criteria were not included in this study.

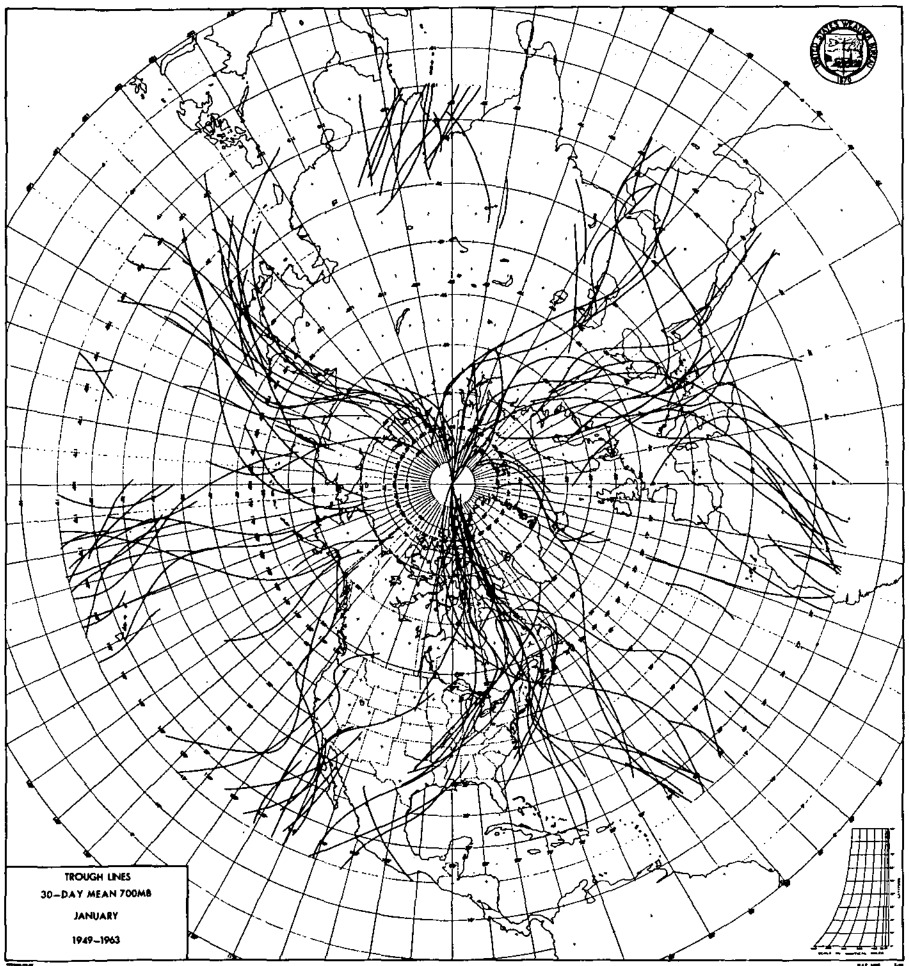

FIGURE 1

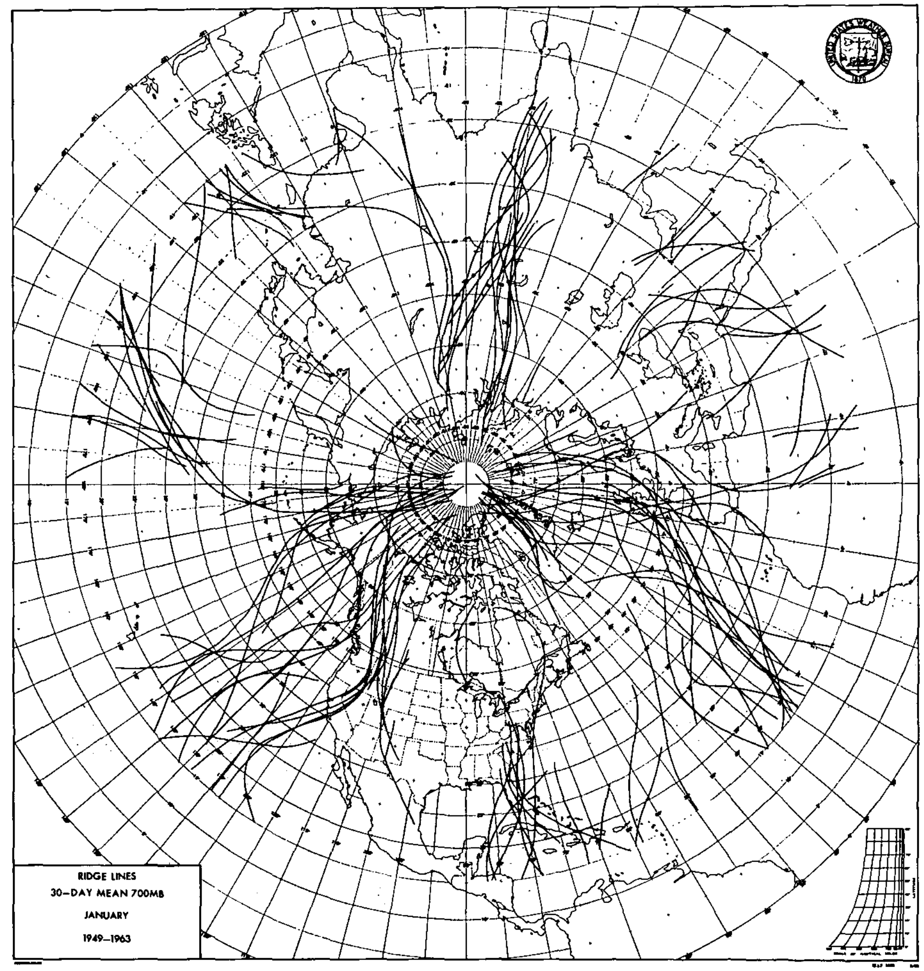

FIGURE 2

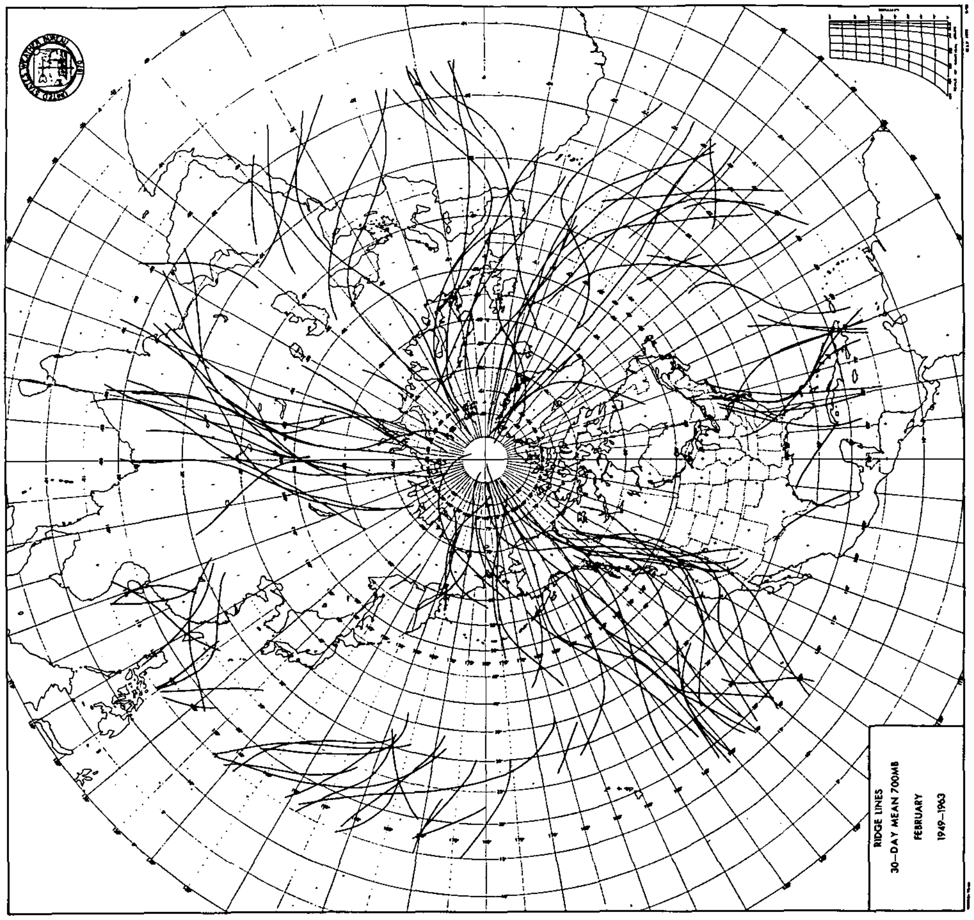

FIGURE 4

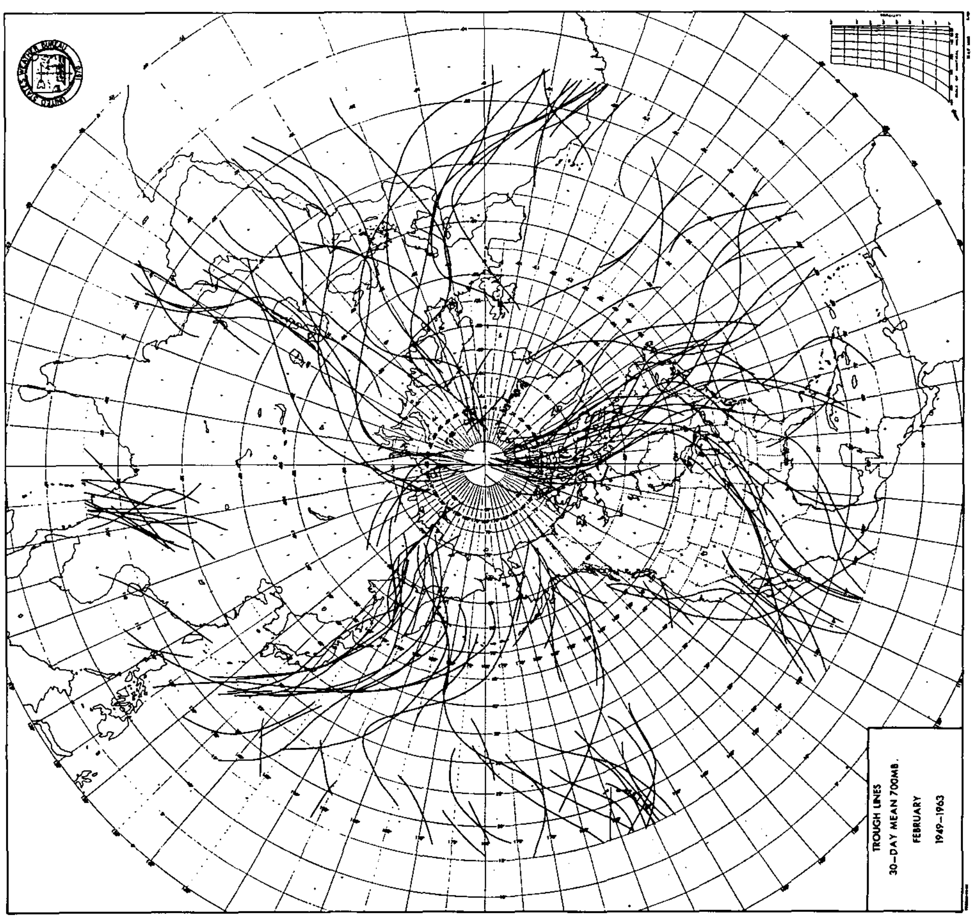

FIGURE 3

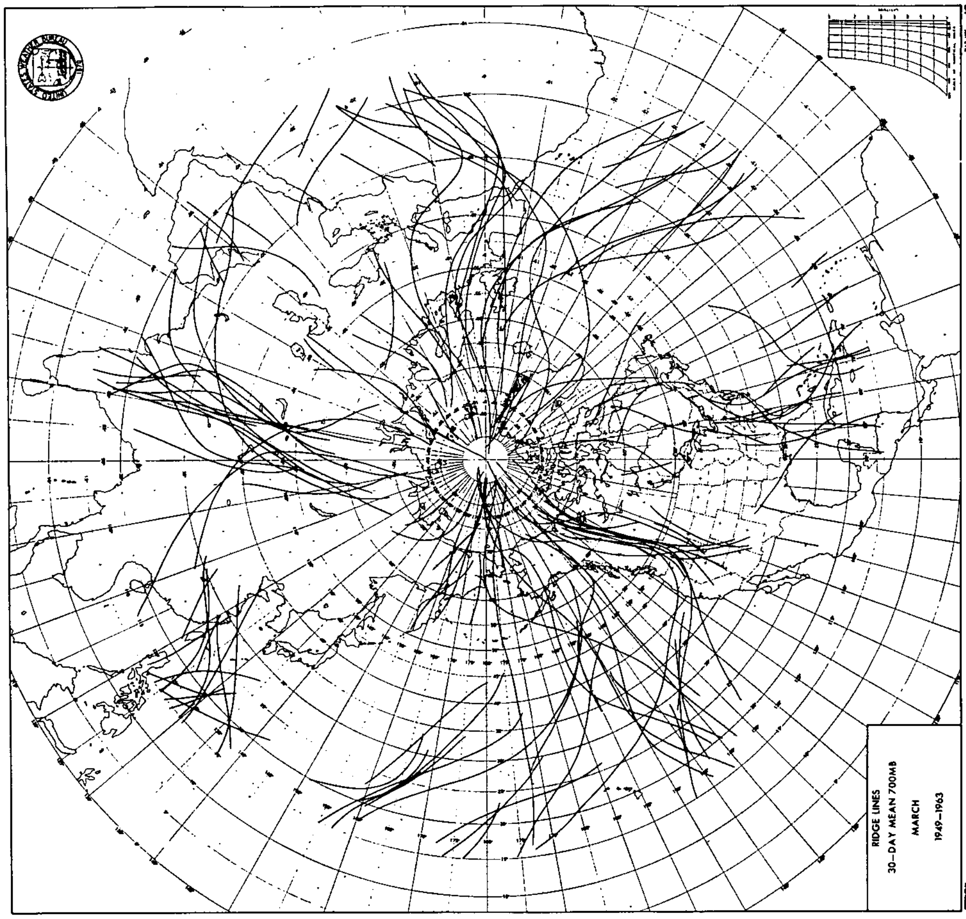

FIGURE 6

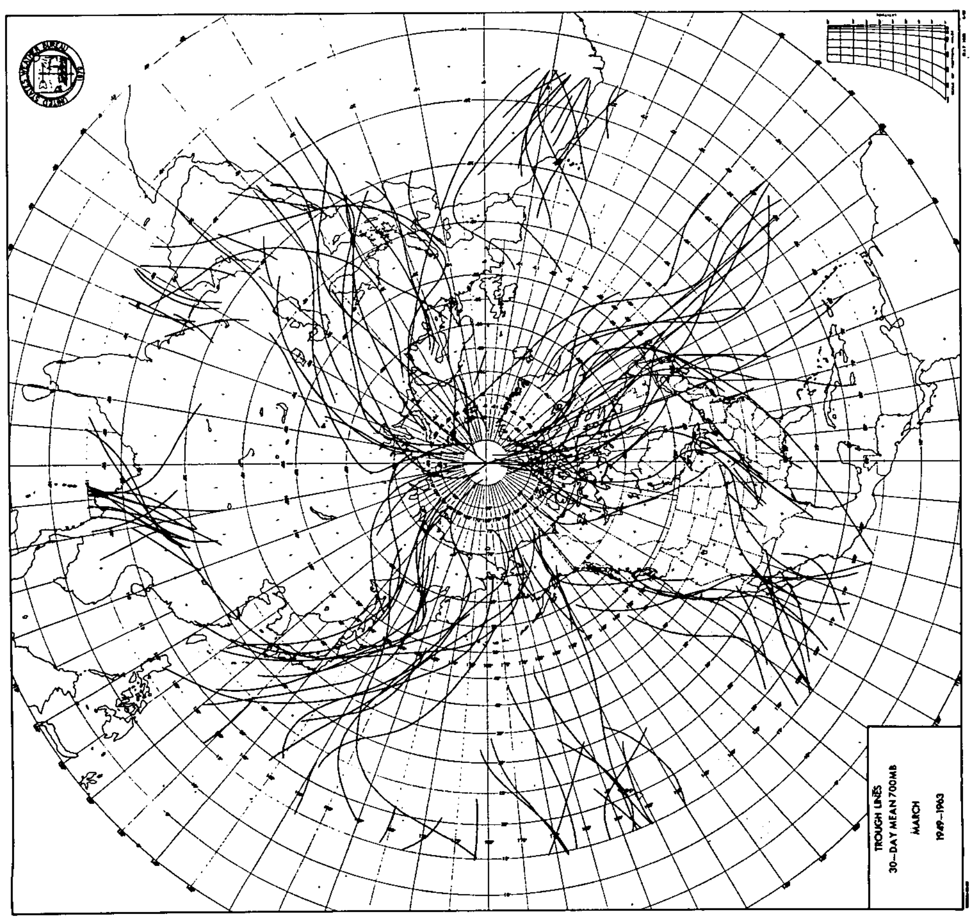

FIGURE 5

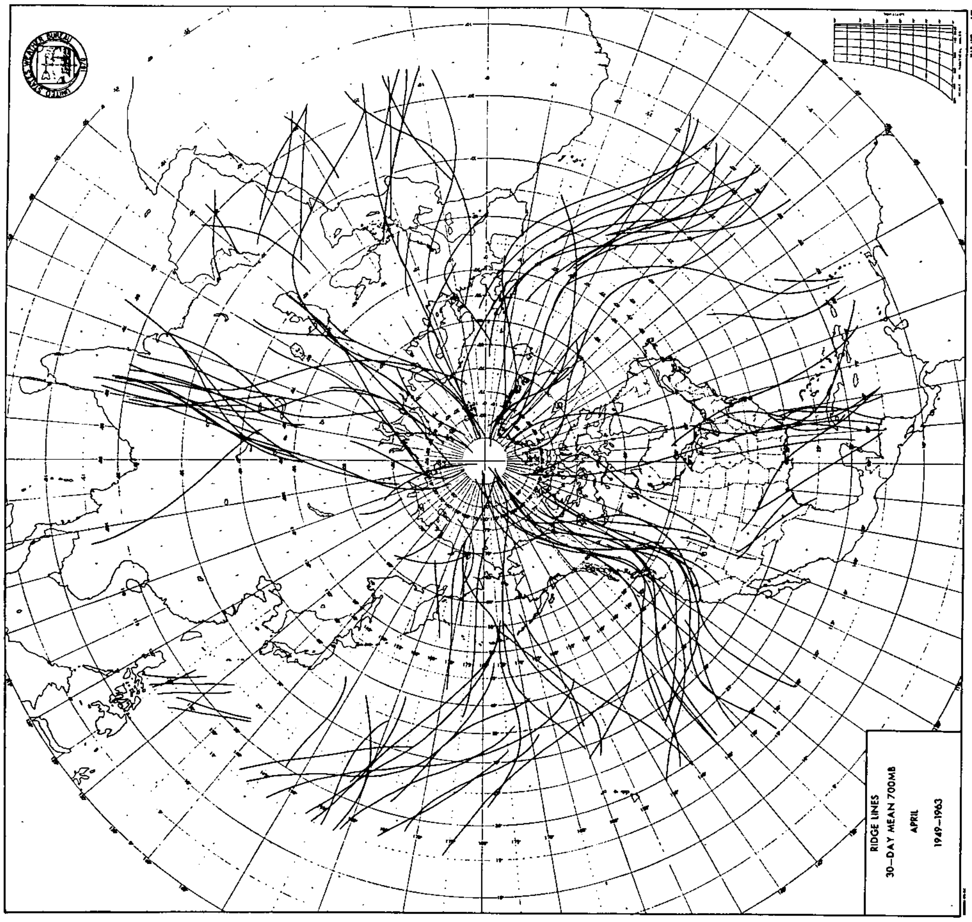

FIGURE 8

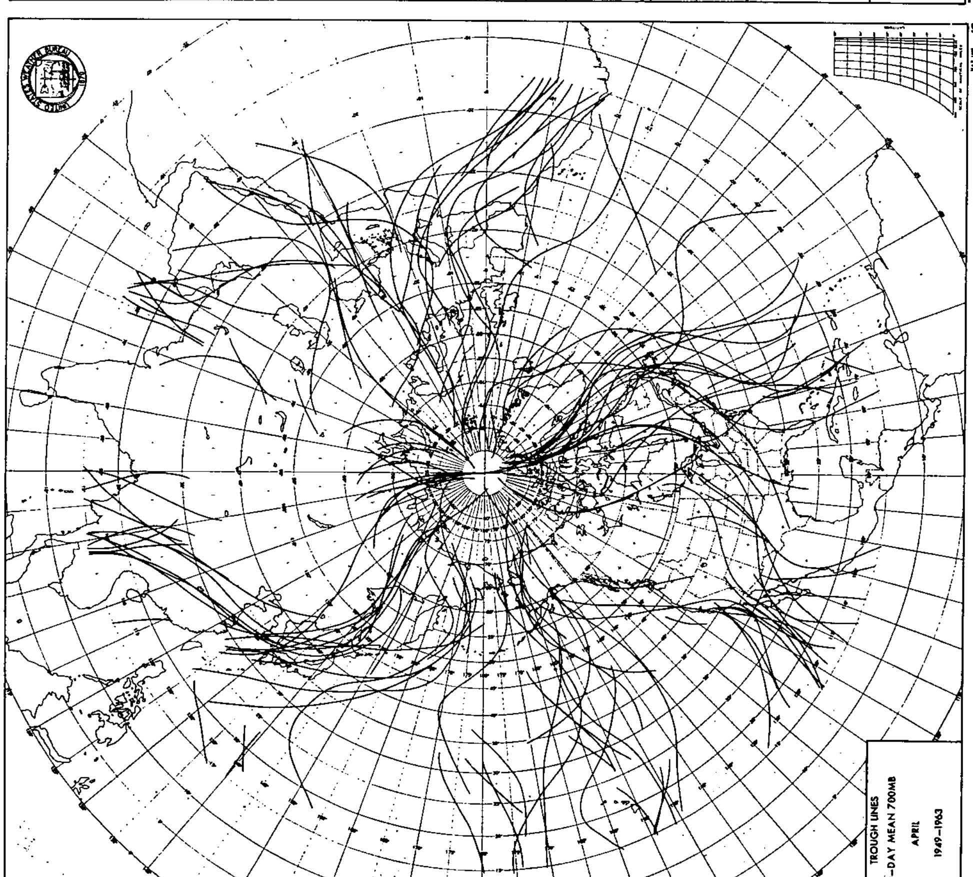

FIGURE 7

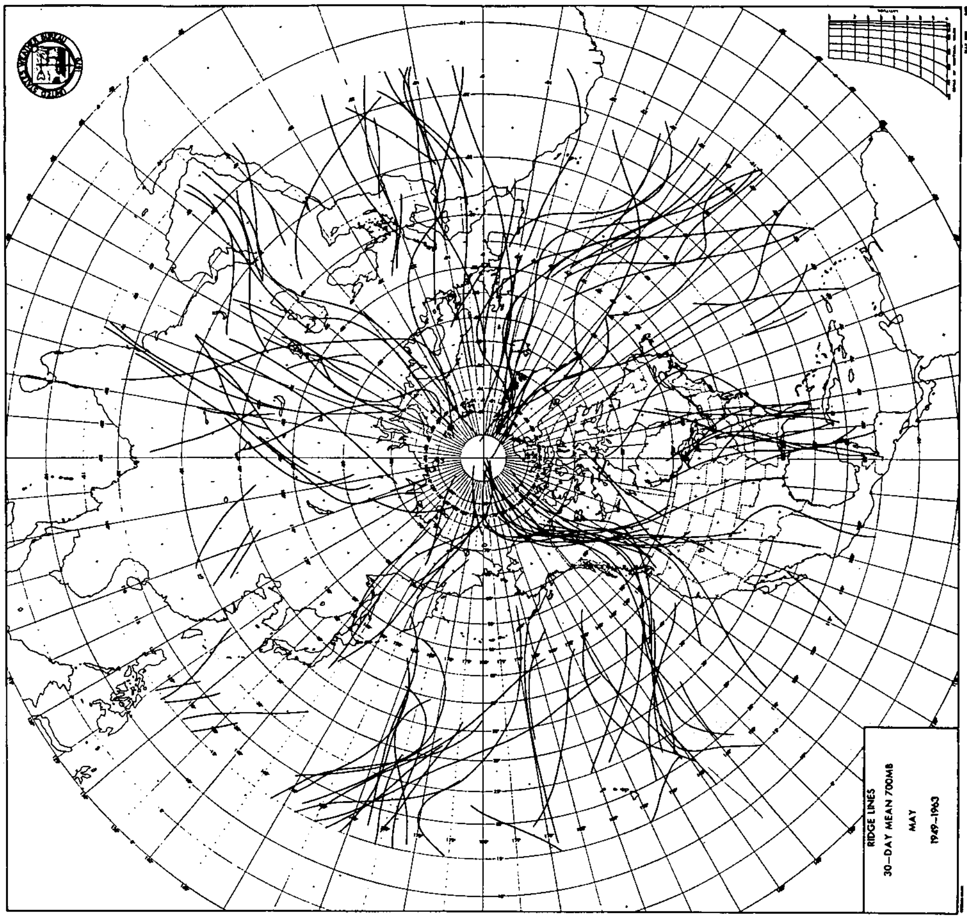

FIGURE 10

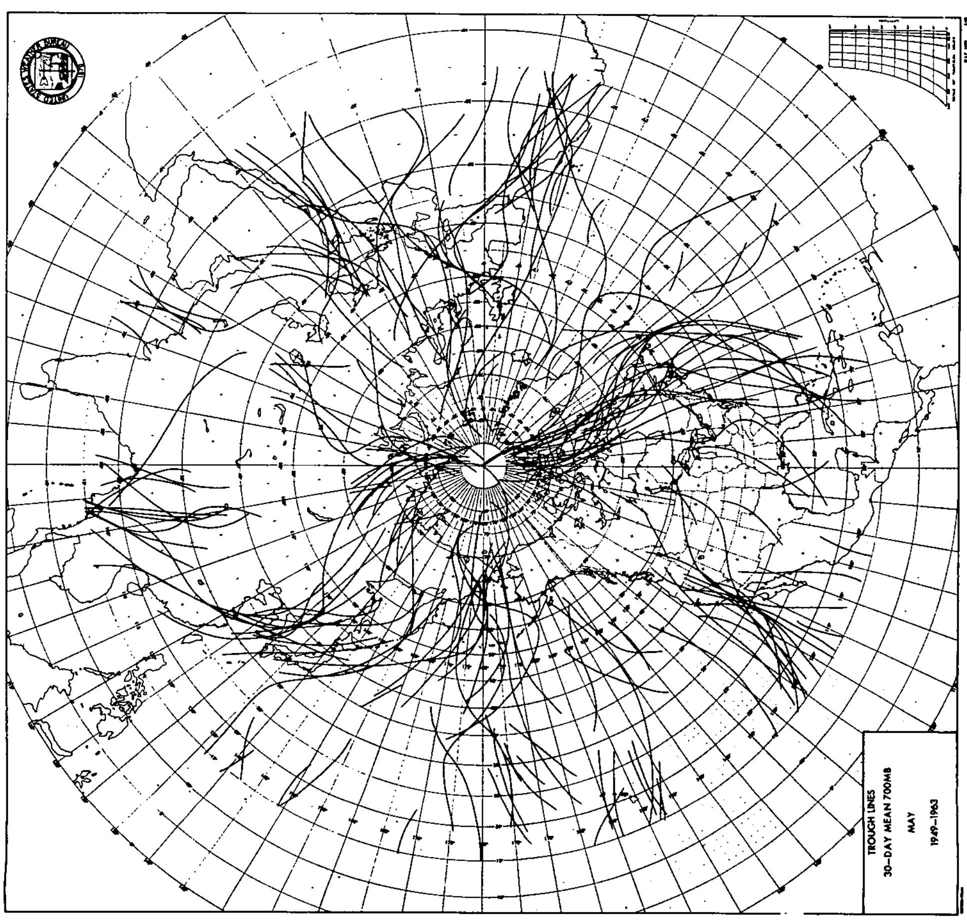

FIGURE 9

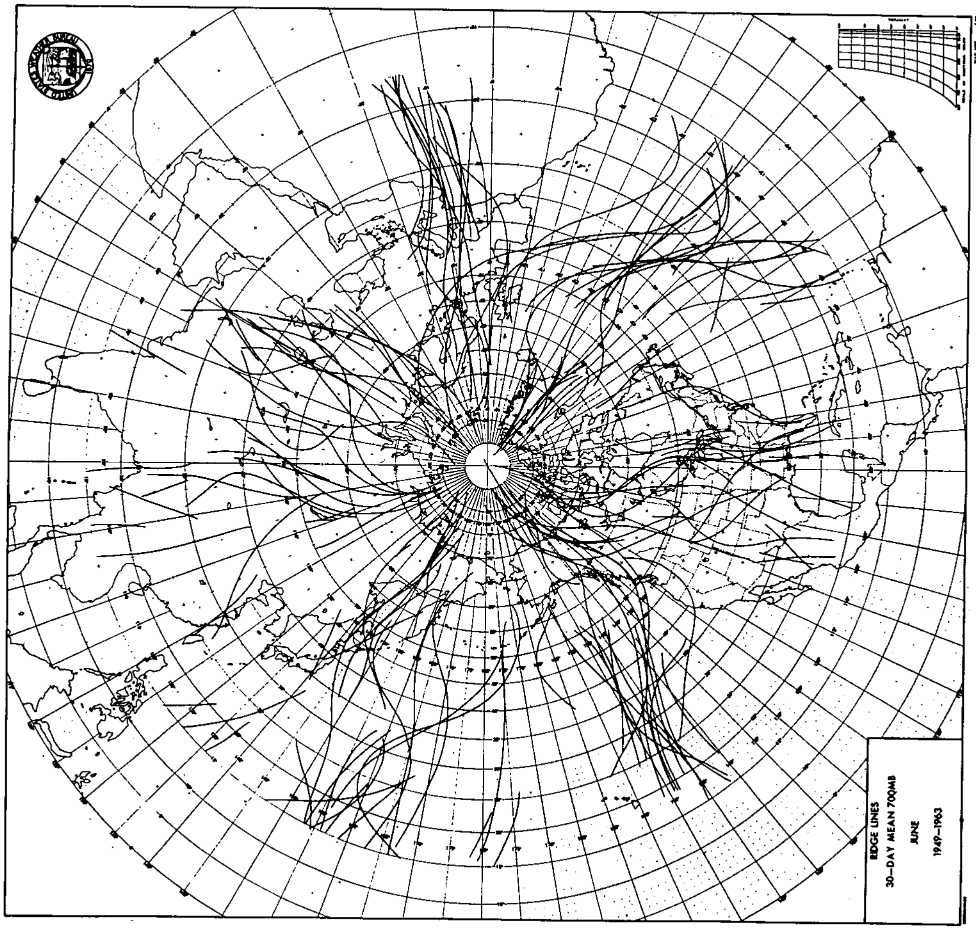

FIGURE 12

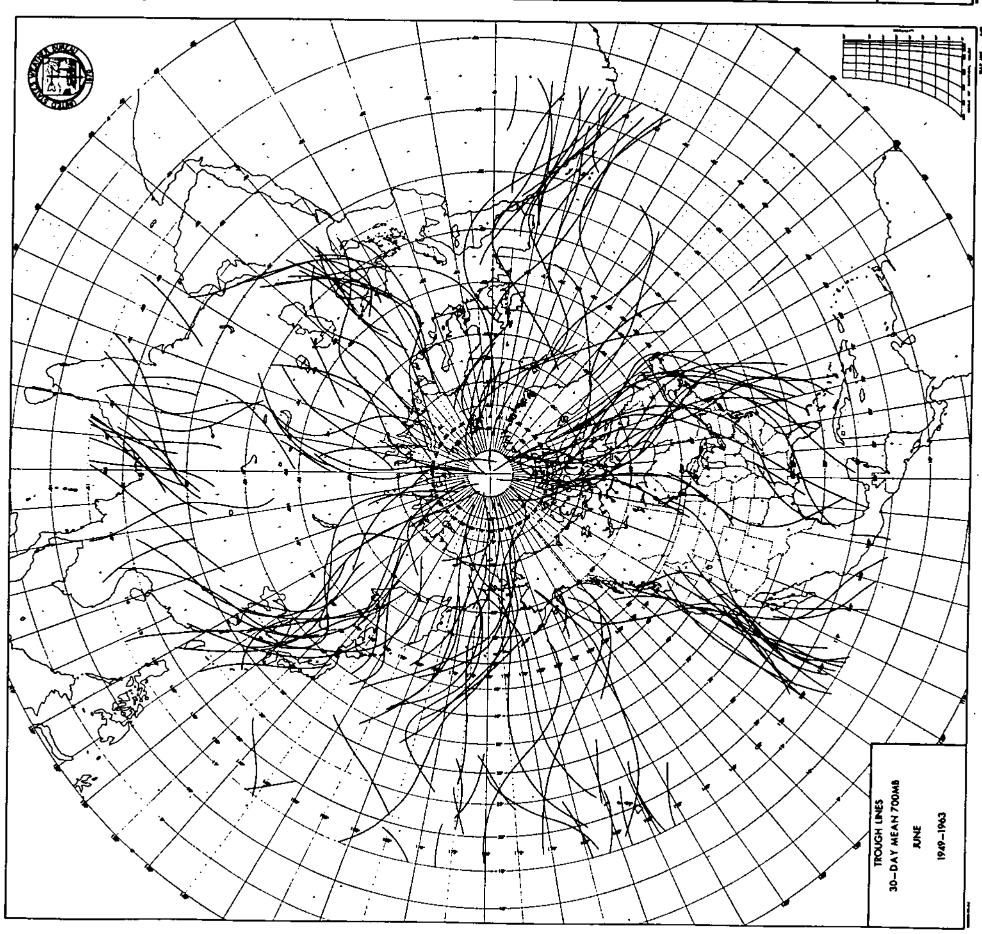

FIGURE 11

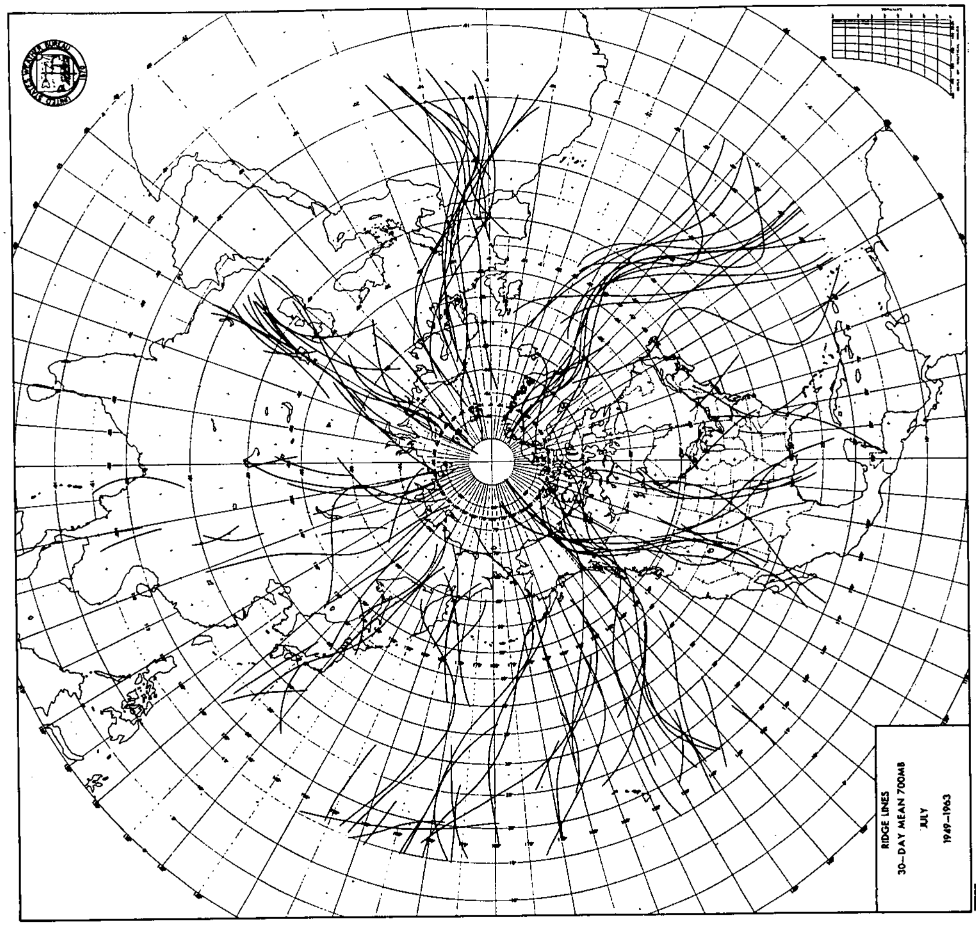

FIGURE 14

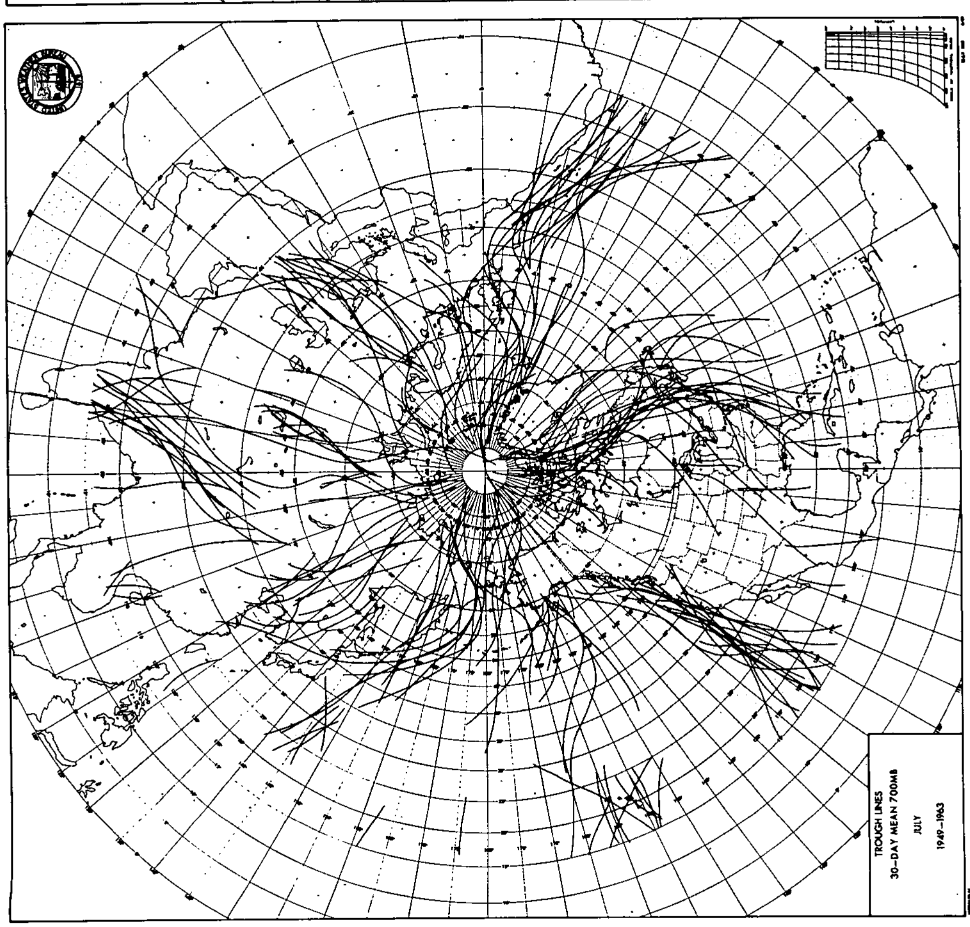

FIGURE 13

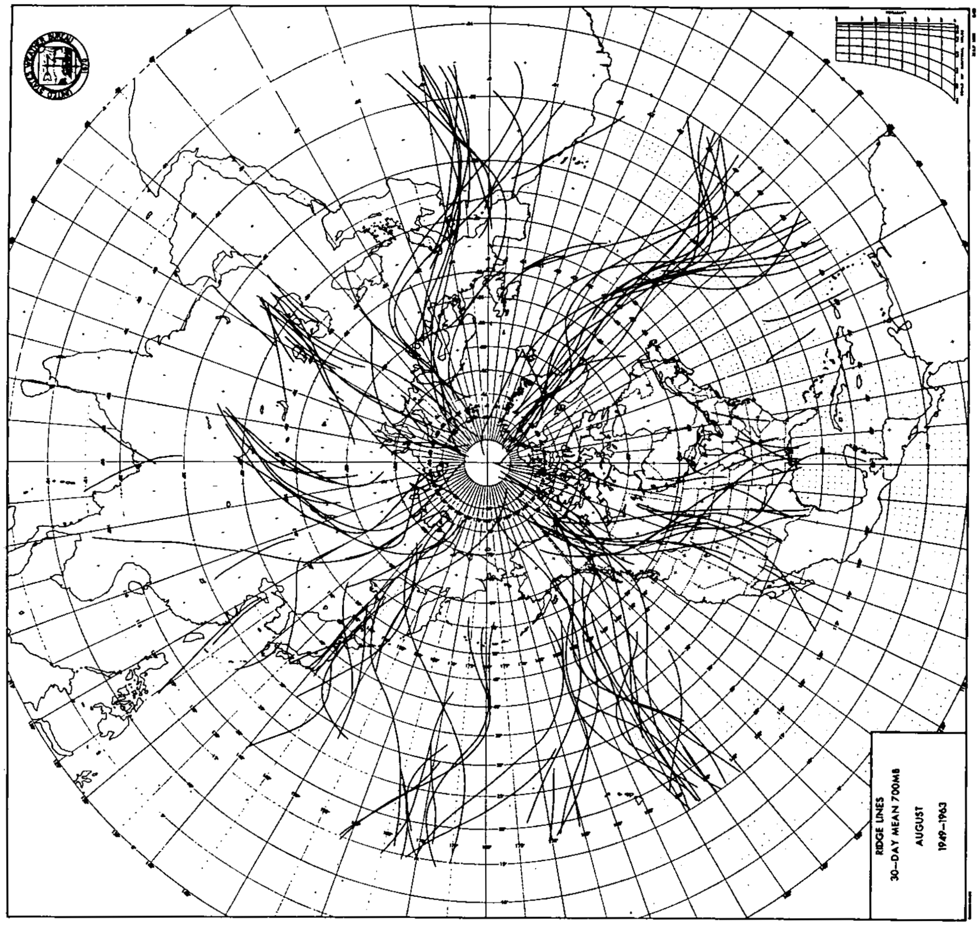

FIGURE 16

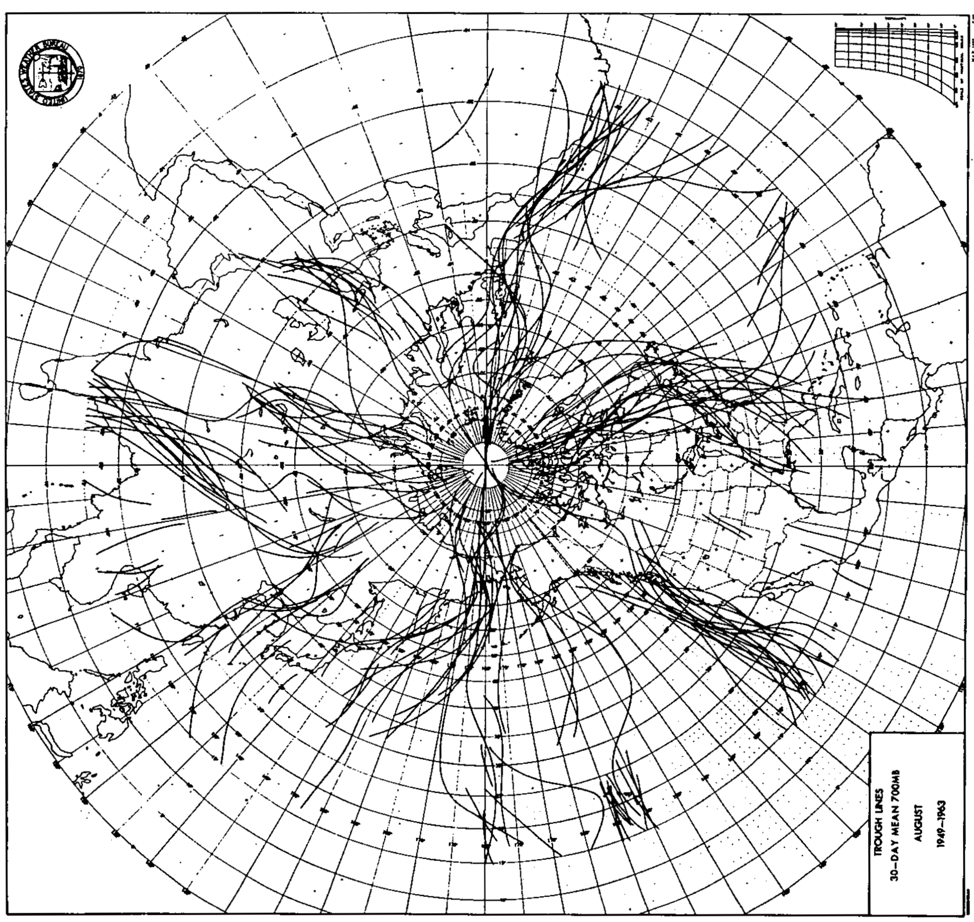

FIGURE 15

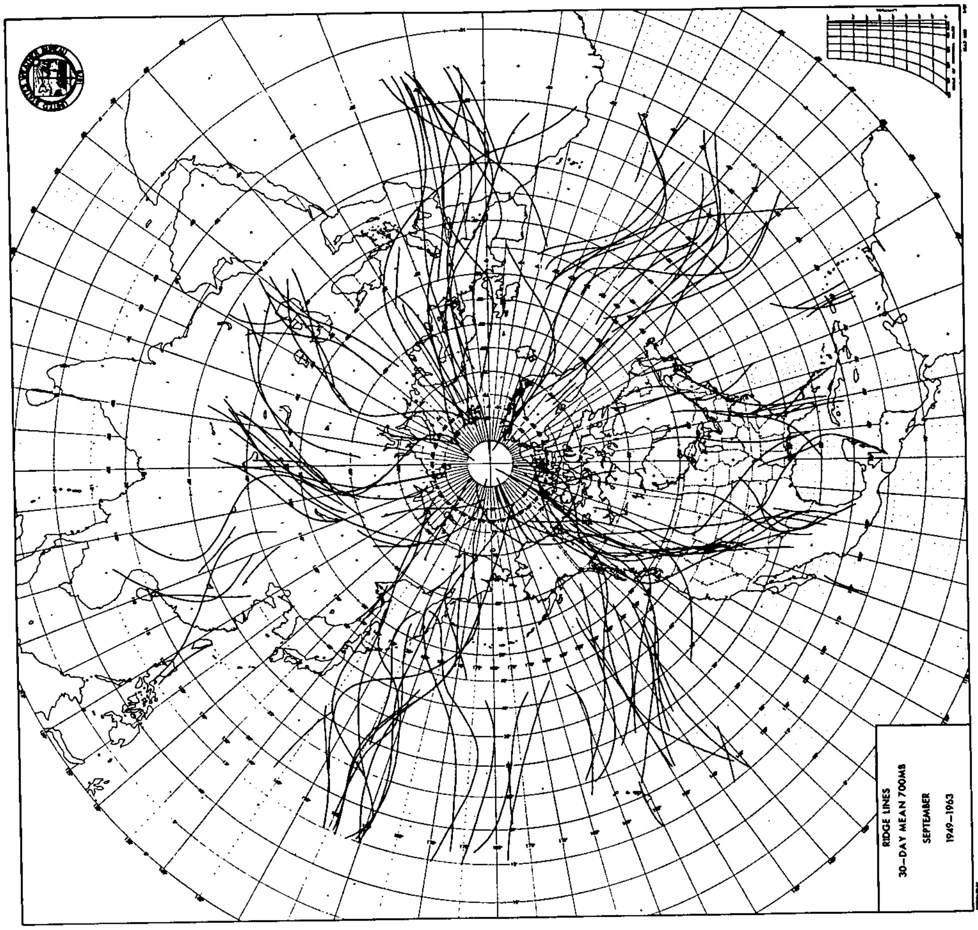

FIGURE 18

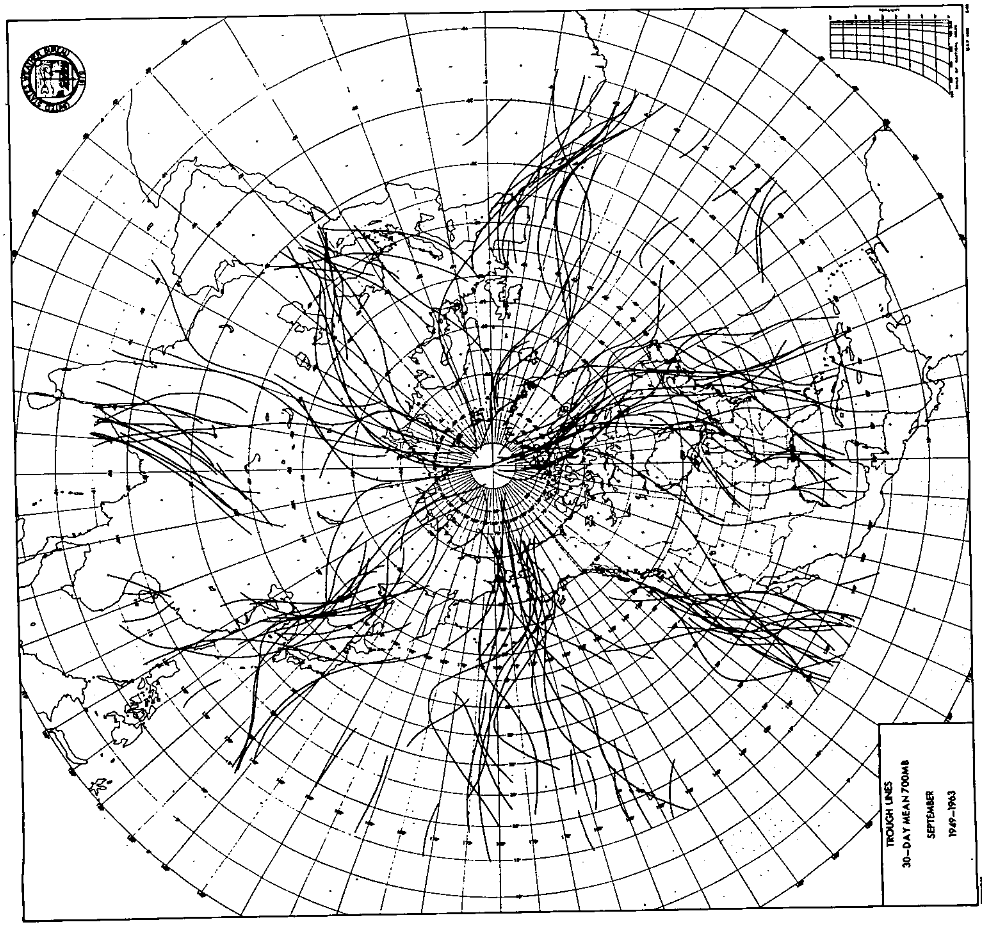

FIGURE 17

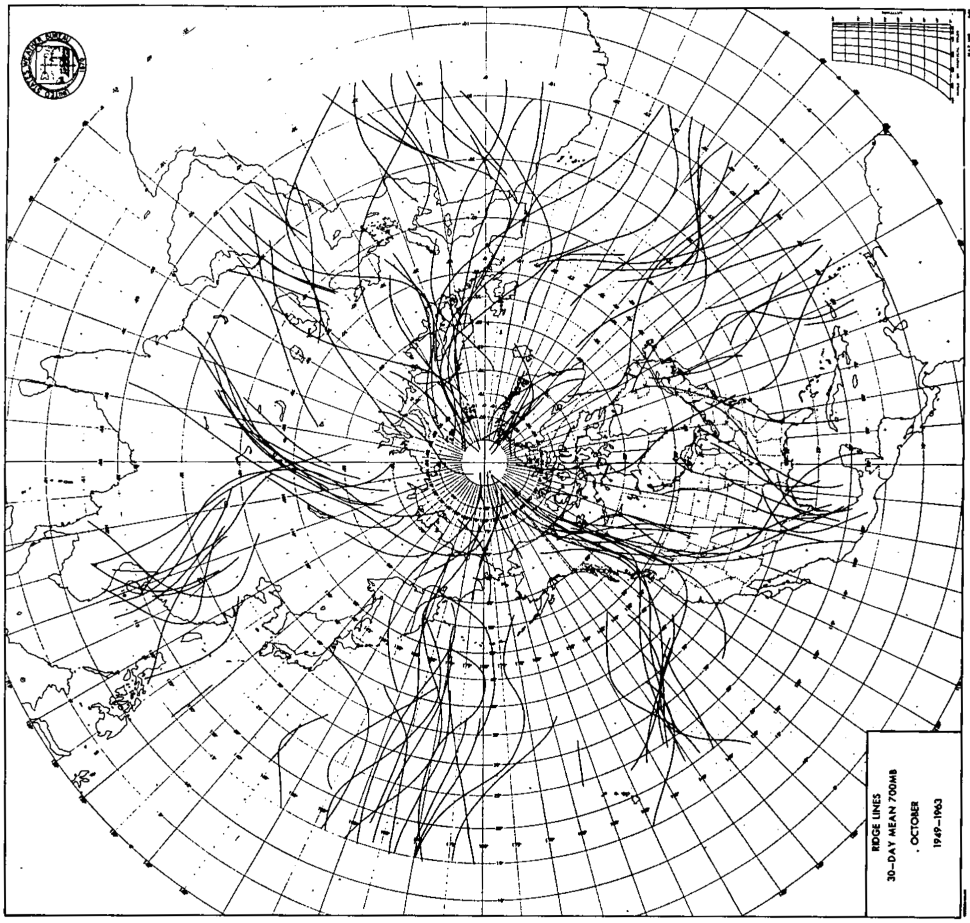

FIGURE 20

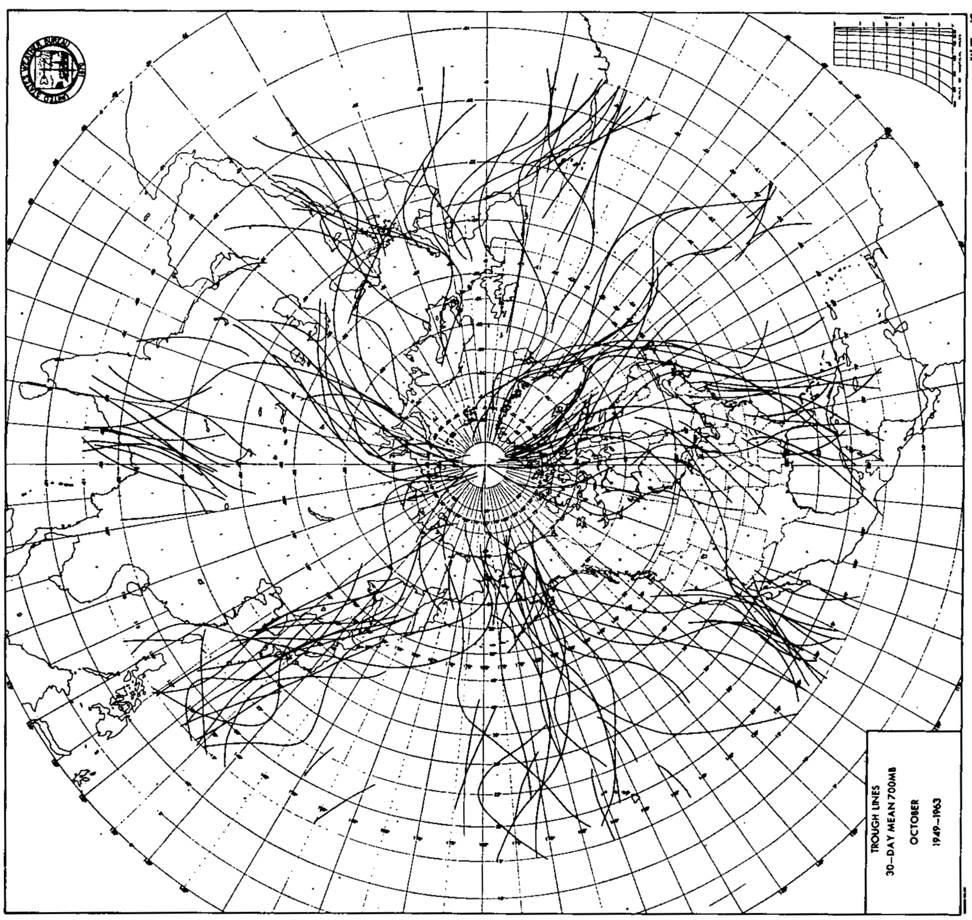

FIGURE 19

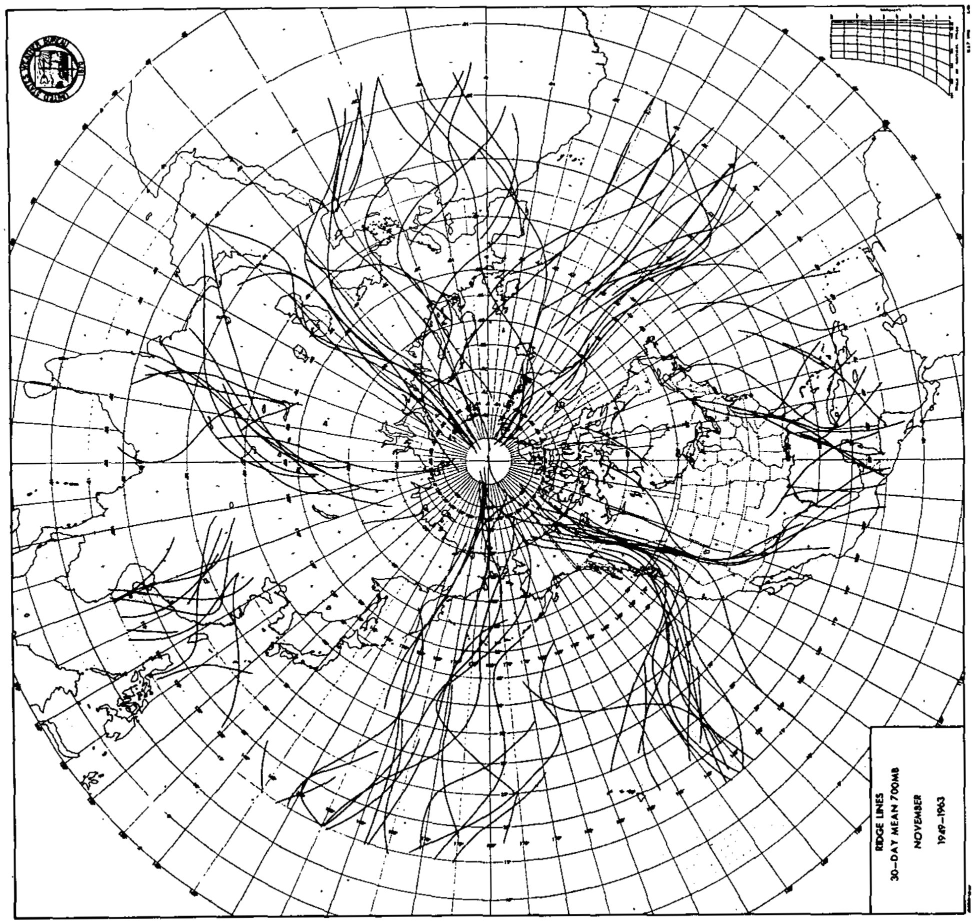

FIGURE 22

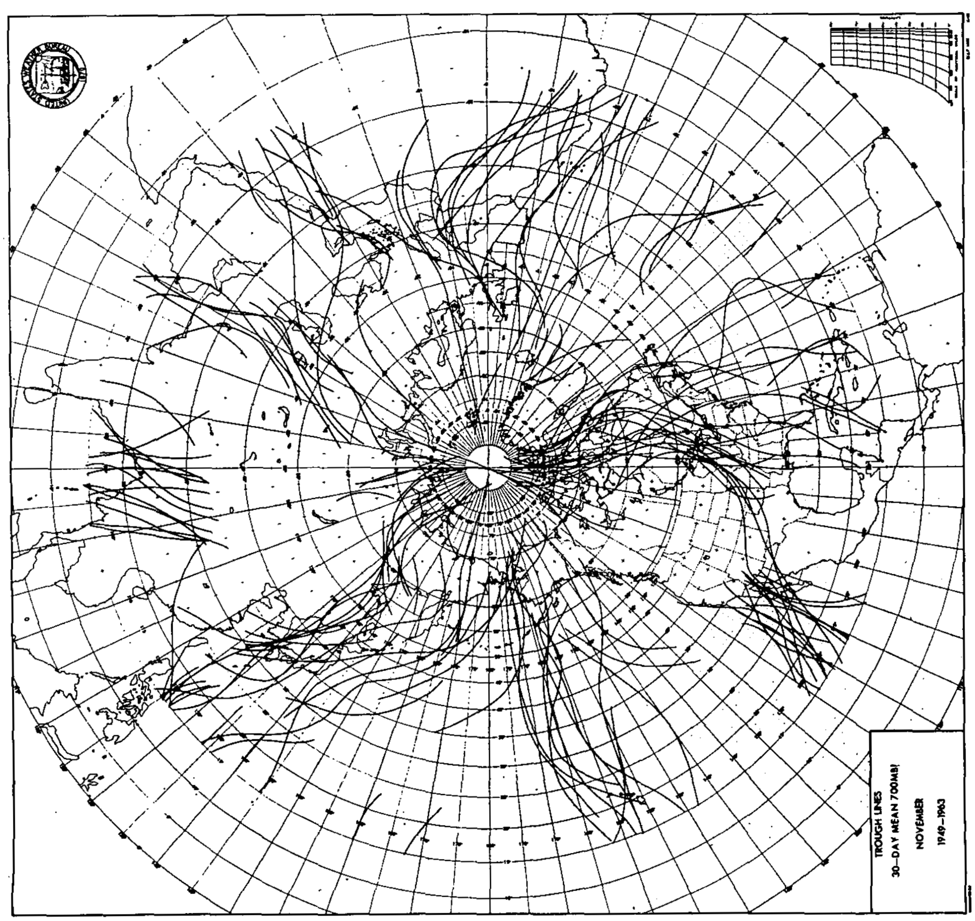

FIGURE 21

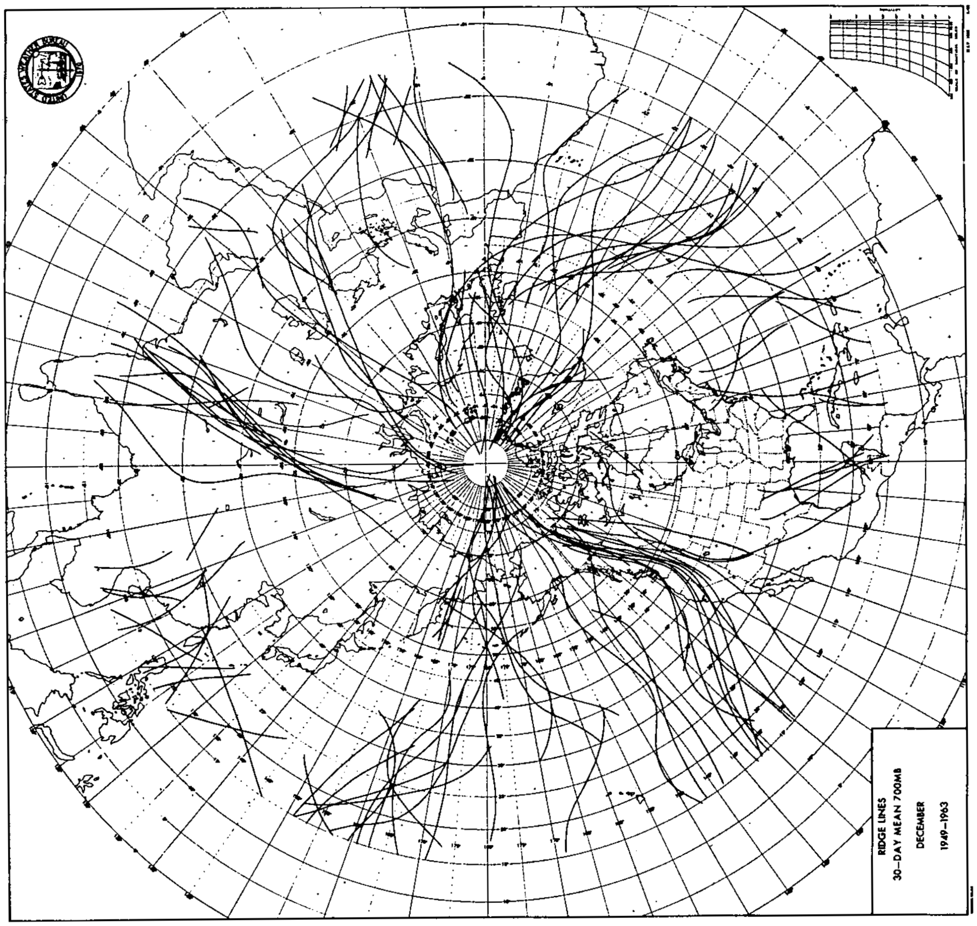

FIGURE 24

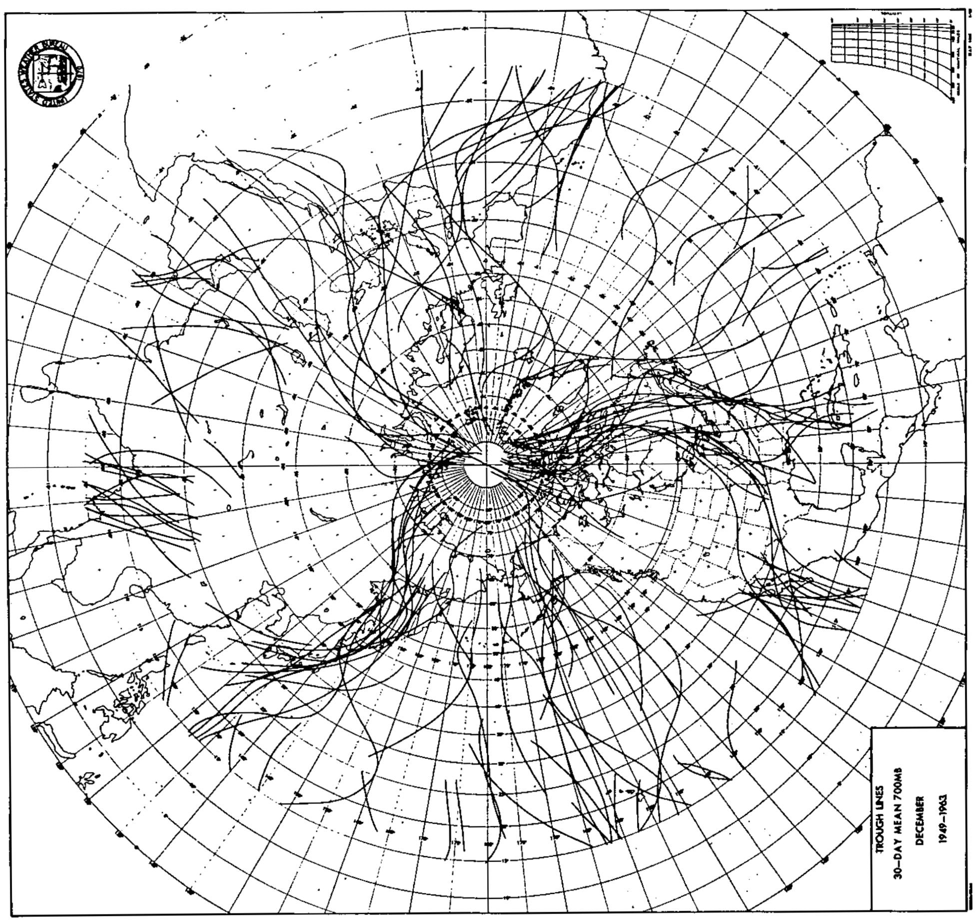

FIGURE 23

30-day troughs and ridges. There was some disparity in certain months, i.e., July and August when there was a strong preference for full-latitude ridges (figs. 14, 16) that extended into Greenland from lower latitudes. These ridges over Greenland occurred at least 60 percent of the time compared with 10–20 percent earlier. Troughs south of Iceland decreased from about 40 percent to less than 20 percent.

EUROPE AND AFRICA

Troughs in Europe were spread rather diffusely from the Atlantic to the Caspian Sea in most months. During the summer, however, there was an apparent migration of troughs to the Atlantic coast of Africa and another marked concentration near the Black Sea. From June to September (figs. 11, 13, 15, 17) the Mediterranean Sea, frequent site of troughs in other months, became an area of very low frequency. Persistent ridging in the western Mediterranean prevailed in the warm months.

United Kingdom and Scandinavia had few monthly mean troughs nearby. In June, July, and August (figs. 11, 13, 15) troughs were at a maximum, probably associated with the greater frequency of ridges over Greenland in these months as discussed above. Generally, however, Scandinavia, the Norwegian Sea, and United Kingdom were dominated by ridging. This was also indicated on recently derived 12-year mean 700-mb. charts [7]. These charts showed marked cyclonic curvature here in the summers and anticyclonic in other seasons.

Comparison with the 1958 study indicates ridges in northwestern Africa in July (fig. 14) were more than twice as frequent as before. Troughs near the United Kingdom were observed in about 40 percent of the Augusts in this study (fig. 15), but in less than 10 percent earlier.

ASIA

Characteristics of the Pacific coastal regions of Asia were similar to those of the east coast of North America. Here was a tremendous source of heat in the cooler months. This and the immense cold source of the continent contributed to the strong baroclinic zone. Thus troughs were frequent in this area except in July and August (figs. 13, 15). The minima in these months were associated with the reversal of the usual temperature gradient from ocean to land.

Another area of persistent troughing was the vicinity of Burma where troughs were semi-permanent except in July, August, and September (figs. 13, 15, 17). In those months troughs migrated to India as the southwest monsoon became most intense. During the monsoon a ridge was prevalent over Central Asia between 40° and 60° N. lat.

An unusual feature of Asia was the broad area in the eastern portion in which there were neither troughs nor ridges in the cooler months. This also occurred in the Northern Plains of the United States. In northeastern Africa the same condition prevailed, but in the warmer months. There were other areas where in some months there were neither troughs nor ridges, but those areas were not extensive.

PACIFIC OCEAN

Extreme eastern and western portions of the Pacific Ocean have been discussed previously, but there were additional notable features.

Trough lines near the Hawaiian Islands were distributed rather widely in most months. The Kona season was not clearly defined by a maximum number of troughs near Hawaii in the winter months. In January there was a grouping of troughs near 170° W. long., but in December and February there was an almost chaotic dispersion of trough lines. In the warmer months the majority of troughs appeared to be easterly, but there were some troughs that were extensions of middle- and high-latitude troughs. Connections to middle-latitude activity were at a maximum in November (fig. 21) about half the time surveyed. It should be noted that the Hawaiian troughs lay about half way between the troughs in the extreme eastern and western Pacific. Apparently this is a natural compensation for what would otherwise be excessive wave spacing in those latitudes.

A favored area for troughs in middle and higher latitudes was from the Bering Sea southward. This was especially noticeable as the frequency of troughs along the west coast of North America increased and as there was a decrease in troughing along the east coast of Asia.

Ridges were observed in the eastern Pacific in all months although there was some western displacement in the warm months as the trough along the American west coast became more active. This ridging was usually the southern continuation of the ridge over western North America. Another maximum of ridges occurred in the west central Pacific associated with the western lobe of the subtropical anticyclone.

REFERENCES

1. J. M. Craddock, H. Flohn, and J. Namias, "The Present Status of Long-Range Forecasting in the World," World Meteorological Organization, *Technical Note* No. 48, 1964, 24 pp.
2. "WMO–IUGG Symposium on Research and Development Aspects of Long-Range Forecasting, Boulder, Colo., 1964," World Meteorological Organization, *Technical Note*, No. 66, 1965, 339 pp.
3. W. H. Klein, "Specification of Monthly Mean Surface Temperatures from 700-mb. Heights," *Journal of Applied Meteorology*, vol. 1, No. 2, June 1962, pp. 154–156.
4. J. Adem, "On the Basis for the Numerical Prediction of Monthly and Seasonal Temperatures in the Troposphere-Oceanic-Continent System," *Monthly Weather Review*, vol. 92, No. 3, Mar. 1964, pp. 91–103.
5. J. Namias, "Problems of Long-Range Weather Forecasting,"

Journal of the Wahington Academy of Sciences, vol. 54, May 1964, pp. 191–195.

6. W. H. Klein and J. S. Winston, "Geographical Frequency of Troughs and Ridges on Mean 700-mb. Charts," *Monthly Weather Review*, vol. 86, No. 9, Sept. 1958, pp. 344–358.

7. J. F. O'Connor, "Hemispheric Distribution of 5-Day Mean 700-mb. Circulation Centers," *Monthly Weather Review*, vol. 92, No. 6, June 1964, pp. 303–315.

[*Received July 26, 1965; revised September 8, 1965*]

CORRESPONDENCE

(Continued from page 704)

work was available to me at the time my paper was in manuscript form. The second of his papers has yet to be published as of this writing. After examining Dr. Tucker's first paper, I am still of the opinion that no correlation has been found. The evidence to which Dr. Tucker refers is apparently contained in his figures 11 and 12 and the associated discussion in the text. Despite careful reading of this area of his paper, I am unable to estimate how much $\overline{v'u'}$ or $\partial(\overline{v'u'})/\partial y$ varies with the choice of one of the three pairs of stations which were used to determine averages of the latter quantity. No statistical test of significance, such as standard deviations from the somewhat erratic averages, is presented. Unless similar results are obtained from each of the three pairs, and, preferably, additional pairs of stations at other longitudes, a real correlation of v' and u' cannot be claimed.

Dr. Tucker's second point is that his non-Fickian momentum flux leads to a vertical velocity which is constant with time provided the vertical eddy viscosity is also invariant in time, whereas Reed derives a vertical velocity of 26-mo. period. If I am expected to state my preference between the two results, then I must say that I prefer Reed's since it follows from a simple form for heat diffusion and from observations of wind and temperature which are far more reliably established than Dr. Tucker's estimates of vertical variation of vertical eddy viscosity, or of $\partial(\overline{u'v'})/\partial y$. Moreover, Reed has shown quantitatively that his vertical velocities are consistent with the now well-established oscillation of total ozone amount over the equator.

With respect to Dr. Tucker's third point it may well turn out that QK_{mz} (if such a formulation is applicable at all) varies with height in a way which is related to $\partial(\overline{v'u'})/\partial y$, if and when reliable observations of the latter quantity become available.

[*Received July 21, 1965*]

Further Comments

G. B. TUCKER

Bureau of Meteorology, Melbourne, Australia

When preparing comments on Professor Staley's paper I was aware that my second paper cited was still in the press. However, it was included because it is a sequel to my first paper, is essentially relevant, and will be published before these comments appear. It is perhaps unfortunate that all the points raised in the first paragraph of Professor Staley's reply are dealt with therein.

It was certainly not my intention to ask for an opinion on the relative merits of two different treatments—both of which have appeared in another journal. Professor Staley dealt with a Fickian treatment of momentum which, he argues, appears inapplicable. I agree. But his remarks carried the implication that no non-Fickian treatment existed. I merely sought to draw attention to such a treatment in the literature.

I also agree that it *may* be inapplicable to use the concept of a vertical eddy viscosity. Nevertheless, Professor Staley uses this concept, and, whatever the form of $\partial\overline{v'u'}/\partial y$ turns out to be, there will still remain an important association between the two terms which was not apparent in the paper.

[*Received August 27, 1965*]